

Life Assessment for Creep and Fatigue of Steam Turbine Blisk

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Abstract— *Steam Turbine Rotors are one of the key sectors among rotating machinery heavy engineering components. These machines operate at a constant speed at high pressure and high thermal gradients at the initial stages. One of the main factors concerning the mechanical integrity of these rotors is the interface between the blade and the disk. The contact region between the blade and the disk happens to be the most critical zone in the blade rotor. In order to manage high stress gradients at the blade root region, the rim of the disk is made heavier. The mass of rim of the High Pressure stage collectively makes the design bulky. Apart from the design being bulky, the chances of the contact region leading to crack initiation due to high thermal gradient and enormous centrifugal force over a period of time can lead to fatigue creep interactions reducing the life of the disk. In the present work, one small effort is made to integrate the blade and the disk to form Integrated Blade Rotor commonly known as "BLISK" for the first stage blades. And reduce the Mass of the rotor by scooping the uniform disk.*

Keywords— *Blisk, Integrated bladed rotor, Thermal gradient, Creep, Fatigue.*

I. INTRODUCTION

Turbo machines are devices that Transfers energy from flowing fluid to rotating component. Turbines are the basic types of turbo machines. The thermal energy of the steam is extracted by steam turbines to do the mechanical work i.e. to rotate the output shaft. The high pressure-high temperature steam is expanded in the steam turbine to low pressure low temperature. Energy is extracted while this expansion process. The extraction of energy from flowing fluid is achieved by set of components such as rotors and blades. The flow of steam through the series of blades turns the rotor continuously. The steam will expand and cools as it flows over the turbine blades. The sturdy axle running at the center of the turbine is called rotor transfers mechanical energy to whatever the turbine is driving. The turbine blades are so important part of turbine which if not properly designed it may lead to catastrophic failure of the turbine. And also it

should be designed in such a way that it should extract as much energy as possible. The high pressure-high temperature superheated steam passes through the turbine blade while expanding and rotating the blades. After expansion the low pressure-low temperature steam exits through the exhaust.

If we take a closer look at one of the blade, we can see that it is a collection of airfoil cross section from hub to tip. These airfoils are designed in such a way that while fluid passes through airfoil blade it induces low pressure on bottom surface and high pressure at top surface[7]. A turbine blade rotates because of this pressure difference which induces resultant upward force, hence converting the fluid flow energy to mechanical work. In most of the axial flow Turbomachinery used today blade and disks are manufactured separately [3]. The interface between the blade and disk is highly stressed area and the major concern is the mechanical integrity of the blade and disk. In mechanically attached blade and disk the area of interface between blade and disk is highly and complexly stressed [3]. And attention needs to be paid at blade root where the high stress gradients may initiate crack and eventually leads to failure. To manage this, the disk rim is made heavier. The weight of each rim makes the design bulky. But the contact region is still exposed to high thermal gradient and subjected to high centrifugal pull which may lead to crack initiation leading to fatigue creep interaction over a period of time.

The term "BLISK" is an acronym composed of words BLADE and DISK. Blisks are also called as Integrated Blade Rotor (IBR) [1]. It means Blade roots and locating slots are not required anymore. Blade and disk act as one component. Elimination of the dead weights of blade root and disk lug leads 30% reduction in weight [11]. In mechanically attached blade and disk the area of interface between blade and disk is highly and complexly stressed [3]. And attention needs to be paid at blade root where the high stress gradients may initiate crack and eventually leads to failure. Bladed disk are one of the critical component in a steam turbine. To eliminate this criticality of contact region between disk and blade, Blisk are introduced. As of now, many works have been done on blisk

for aero engines. The main emphasis of this is to evaluate the blisk adaptation in the steam turbines using Finite Element Method.

II. LITERATURE SURVEY

If we take a closer look at one of the blade, we can see that it is a collection of airfoil cross section from hub to tip. These airfoils are designed in such a way that while fluid passes through airfoil blade it induces low pressure on bottom surface and high pressure at top surface[7]. A turbine blade rotates because of this pressure difference which induces resultant upward force, hence converting the fluid flow energy to mechanical work. In most of the axial flow Turbomachinery used today blade and disks are manufactured separately [3]. The interface between the blade and disk is highly stressed area and the major concern is the mechanical integrity of the blade and disk.

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III. PROBLEM DEFINITION

The blade and disks are manufactured separately after which they are mechanically attached to form the rotor part of the turbo machinery. In operating condition, the contact region between the blade and the disk happens to be the most critical zone in the blade rotor. In order to manage high stress gradients at the blade root region, the rim of the disk is made heavier. The mass of rim of the High Pressure stage collectively makes the design bulky. Apart from the design being bulky, the chances of the contact region leading to crack initiation due to high thermal gradient and enormous centrifugal force over a period of time can lead to fatigue creep interactions reducing the life of the disk. Any damage caused during the operating life of the disk proves to be costly design since the rotor cannot be replaced for all stages. The blade failures have been a common occurrence leading to catastrophic failure of turbines. In attempt to eliminate this risk BLISK is introduced.

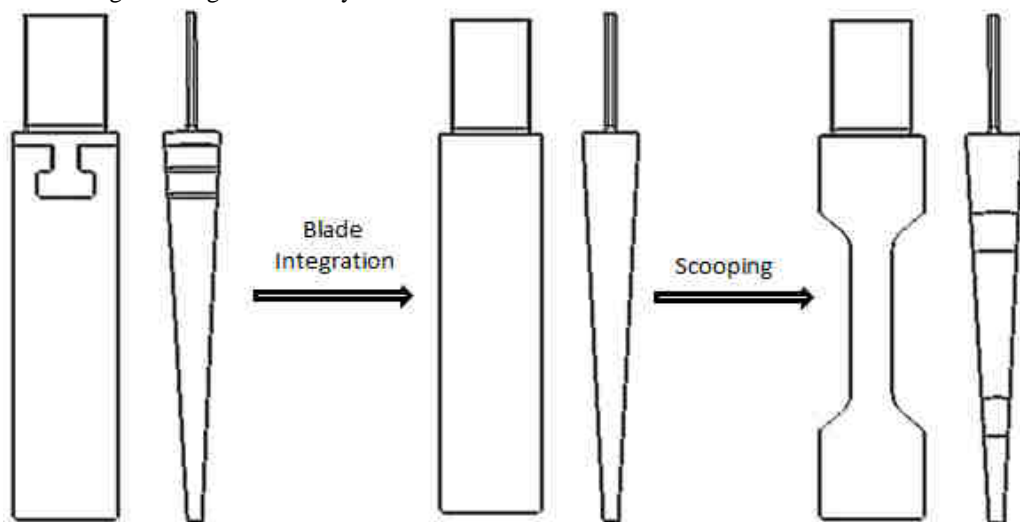


Fig. 3.1: Blade Integration and optimization

Reducing the mass of the rotor is still another challenge. After integrating the disk and blade uniform blisk is scooped as shown in the figure 3.1. For overall stages this scooping will reduce considerable mass of the rotor.

IV. MATERIAL AND METHODOLOGY

Project started off with the detailed study of the process and experiments were carried out and are explained in the literature review chapter, sufficient information about steam turbines and its types was recorded. The Journals and technical papers give us insight about the criticality of blade

and rotor design. As a part of study of Integrated Bladed Rotors (IBR), much work has been done on Blisk in aero engines while not much about Blisk in Steam Turbines. We collected the results, conclusions and future scope of work details and started off with defining the objectives.

TOOLS USED FOR ANALYSIS:

As a part of this project work, commercial CAD and FE analysis tools are used extensively to model and analyze the structural component. The process for generating CAD model for the component, transferring CAD model into FE analysis software, Analysis, Data processing and design improvement is taken up and completed. This has given good insight into the design process, meeting the environment and working well within the constraints.

PRELIMINARY DESIGN CONSIDERATIONS:

Chrome steel is steel mixed with Chromium. The chromium plating adds protection against rusting of the material.

Table 1.1 Preliminary design considerations of integrated blade

Material	Chrome steel
Mass density	7850 kg/m ³
Poisson's ratio	0.3
FOS	1.68
Young's modulus (E)	2.1*10 ⁵ MPa
Tangent modulus (ET)	5500 MPa
Yield strength	550 MPa
Ultimate tensile strength	784.8 MPa
Operating speed	12000 rpm

CAD MODELLING:

Figure 1.1 shows the CAD model required for the analysis is developed in the Ansys Design Modeler application which is available in Ansys workbench. Cyclic symmetry nature is present in many mechanical structures. By taking advantage of this, cyclic symmetry analysis is the best option to reduce the model size and solution running time. Cyclic symmetry analysis is widely used in rotating machinery components such as blades, vanes, fans etc. The blisk model is meshed effectively.



Fig.1.1: Integrated blade

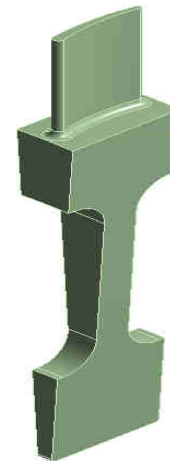


Fig.1.2: I-Section of integrated blade

As cyclic symmetry option is used to carry out the analysis only a single sector of the full 360 degree model is considered. This model is considered as baseline model for the analysis. The mass of this single sector baseline model, $M_{\text{Baseline}} = 0.64507 \text{ kg}$

The rotor is a solid part in actual. But for the analysis, a bore is considered to eliminate the wedge shape which will form at the bottom of the cyclic sector which will lead to mesh uncertainties and inaccurate results.

FE DESCRIPTION:

Mesh convergence refers to the required number of elements or element density to ensure the analysis results are not affected further. Overall mesh convergence defines how fine the meshing should be to obtain accurate results. The mesh is done using tetra mesh with TET10 elements for the entire

model. The fillet region is fine meshed with mapped meshing over blade airfoil.

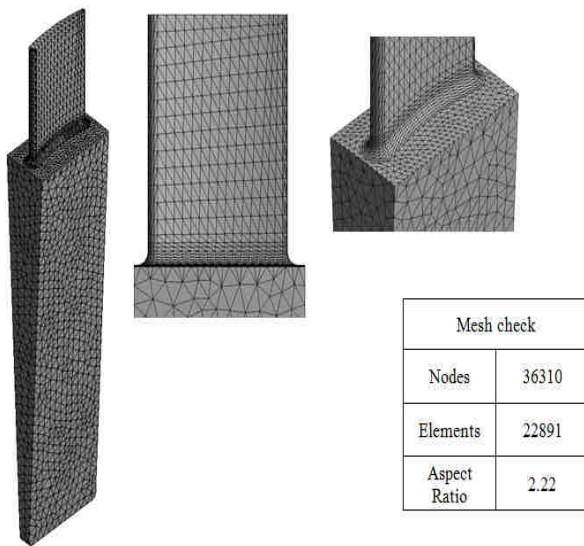


Fig.1.3: FE model of integrated blade

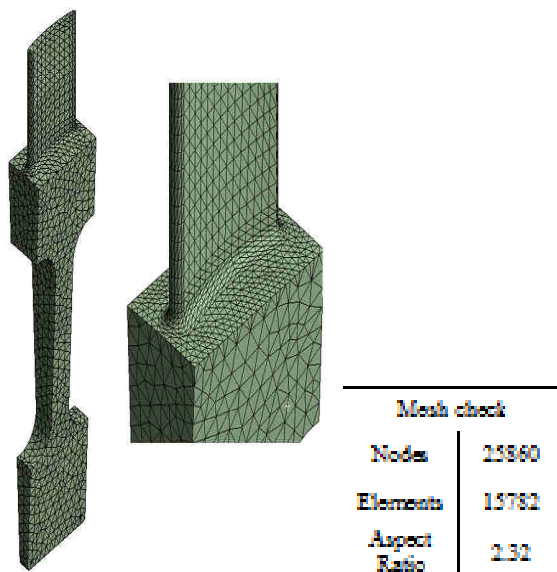


Fig.1.4: FE model of modified I section integrated blade

BOUNDARY CONDITIONS:

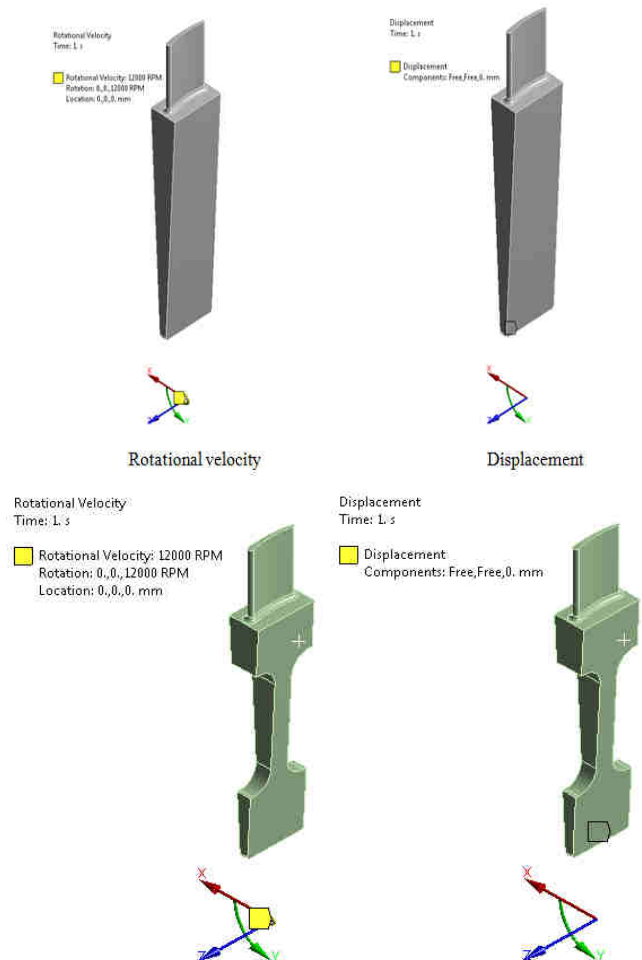


Fig.1.5: Boundary conditions for baseline integrated blade and modified I-section integrated blade

The load is in the form of rotational velocity in rpm. Rotational velocity of 12000 rpm is applied over the Z-Axis on the blisk. Blisk is allowed to breathe in and breathe out radially (X- axis) due to centrifugal force during start up and shutdown. The axial displacement (displacement along Z-axis) of the blisk is arrested. Bilinear analysis with kinematic hardening is run with cyclic symmetry option with above boundary conditions and mesh statistics.

Fatigue strain life parameters for chrome steel show in table 1.2.

Table 1.2: Fatigue strain life parameters for chrome steel [17]

Description	Value
Strength co-efficient	980 MPa

Strength exponent	-0.12
Ductility co-efficient	0.7985
Ductility exponent	-0.6
Cyclic strength co-efficient	1380
Cyclic strain hardening exponent	2

EQUATIONS:

From SWT approach

$$\sigma_{max} \in_a E = (\sigma'_f)^2 (2N_f)^{2b} + \sigma'_f \in'_f E (2N_f)^{b+c}, \dots \dots \dots 1$$

$$411.38 \times 0.00079 \times 2.1 \times 10^5 = (988)^2 (2N_f)^{2 \times -0.12} + 980 \times 0.7985 \times 2.1 \times 10^5 (2N_f)^{-0.12 - 0.6}$$

we find number of life cycles(fatigue life), $N_f = 133388.25$ cycles

From Larson miller parameter approach,

$$LMP = T [\log_{10} t + C], \dots \dots \dots 2$$

$$\text{The Larsen Miller Parameter } LMP = 19.3 \times 10^3$$

$$19.3 \times 10^3 = 808 [\log_{10} t + 20]$$

we find creep life of blisk, $t = 7693.75$ hrs.

Results and discussion for baseline integrated blade and modified integrated blade:

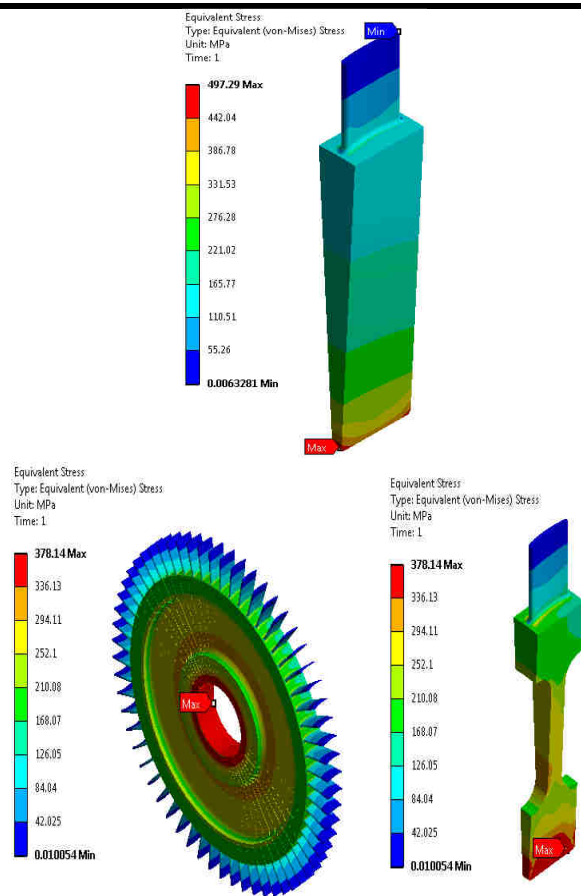
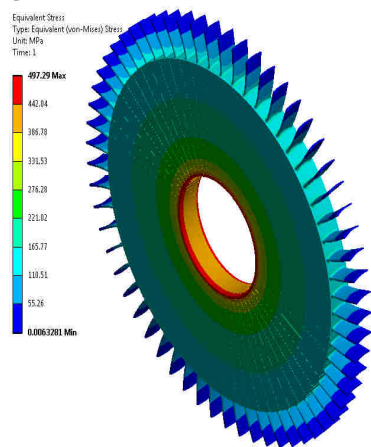
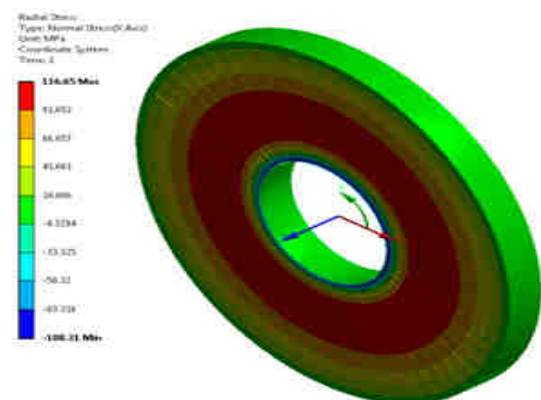


Fig.1.6: Equivalent stress for Baseline integrated blade and modified I-section integrated blade

VALIDATION:



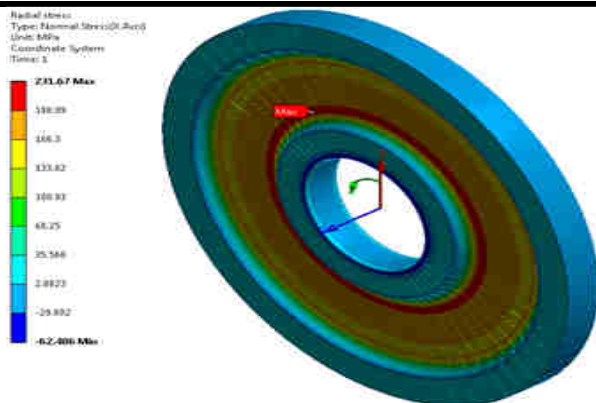


Fig.1.7: Radial stresses of plain disk and optimized I section disk

Table 1.3: Comparative Results for Uniform Disk and I-Section Disk

Stress	Uniform disk	I-section disk
Radial stress(in MPa)	116.65	247.67
Mass(kg)	0.601	0.38183

$$\% \text{ mass reduction} = \frac{0.601 - 0.38183}{0.601} = 36.46\%$$

V. CONCLUSION

Fatigue evaluation using strain life approach shows that the component has 4.5×10^4 low cycle fatigue life. Larsen Miller Parameter is effectively used to find the rupture hour. Creep evaluation shows, when the blisk is operated at 12000 rpm and at 808 K temperature, it can be safely operated up to 7693.75 hours from the obtained results. Nonlinear analysis is carried out using commercial FE package for the Structural evaluation of the steam turbine blisk. The stresses are well below the design limits. The sectional stresses in the blade show the gross yielding does not occur even in over speed condition proving the design to be safe.

The design considerations are taken into account and Design of Experiments is effectively used to study the design space and arrived at optimum I section disk reducing the mass by 36.46%.

VI. ACKNOWLEDGEMENT

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VII. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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